LCA Case Studies

Wet Processed and Dry Phototools in the Manufacturing of Printed Circuit Boards

A Comparative LCA

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Abstract

In the manufacturing of printed circuit boards, the pattern of the copper circuits is first generated on a photographic film (the 'phototool'). These phototools are then used to copy the circuit patterns to the printed circuit boards. In order to generate the circuit pattern on a conventional silver film, the film is exposed to light in a photoplotter and then chemically processed. Mastertool® is a new dry phototool for the production of printed circuit boards. It is based on bismuth instead of silver and does not require chemical processing after exposure. A comparative LCA of Mastertool® and silver film shows that Mastertool® causes significantly less environmental impacts over its entire lifecycle. The underlying reasons are threefold. First, thanks to its improved technical characteristics, Mastertool® has a longer lifetime. Second, its use requires less energy because no chemical processing is needed. Finally, no photographic chemicals are needed and no silver containing chemical waste is produced in the printed circuit board production.

Keywords: Bismuth film, photographic film, Mastertool®; LCA, photographic film, Mastertool®; Mastertool®, photographic film, bismuth film; photographic film, Mastertool®; phototools, silver film, bismuth film, Mastertool®; printed circiut board, Mastertool®; silver film, photographic film, Mastertool®

1 Introduction

The photographic industry has long been based almost exclusively on silver technology. After exposure to light, silver films need to be chemically processed in order to generate a visible image [1]. A new generation of photographic materials that is currently being developed does not require chemical processing after exposure. One of the first sectors where such 'dry' films have already reached the market place is the printed circuit board industry.

Printed circuit boards are used in practically all types of electronic equipment. In the manufacturing process of printed circuit boards, the pattern of the copper circuits is first generated on a photographic film (the 'phototool'). These phototools are then used to copy the circuit patterns to the printed circuit boards in the so-called photoetching process [2].

Conventionally, silver films are used as phototools. In order to generate the circuit pattern on a silver film, the film is exposed to light using a photoplotter and then processed by means of photographic chemicals. Mastertool® is a photographic film that is based on bismuth instead of silver [3, 4]. In order to generate the circuit pattern on a Mastertool® film, the film only has to be exposed to laser light using a photoplotter. No further chemical processing is necessary. Using Mastertool® instead of silver film has direct ecological advantages for the printed circuit boards production industry, since no photographic chemicals are needed and no silver containing waste is produced.

In order to compare the environmental impact of Mastertool® with that of silver film, the perspective may however not be limited to the printed circuit board industry alone. Instead, the entire lifecycles of the two alternatives have to be investigated. This paper presents the results of a comparative LCA between silver film and Mastertool®.

2 Silver and Mastertool® Film

2.1 Description of silver and Mastertool® film

The structures of silver and Mastertool® film are schematically represented in **Figure 1**.

The silver film that is analysed in this study is a typical film produced by Agfa-Gevaert N.V. for applications in the printed circuit board industry. It is known under the name HTR 3 (High Tech Red 3). It consists of a 175 µm thick PET

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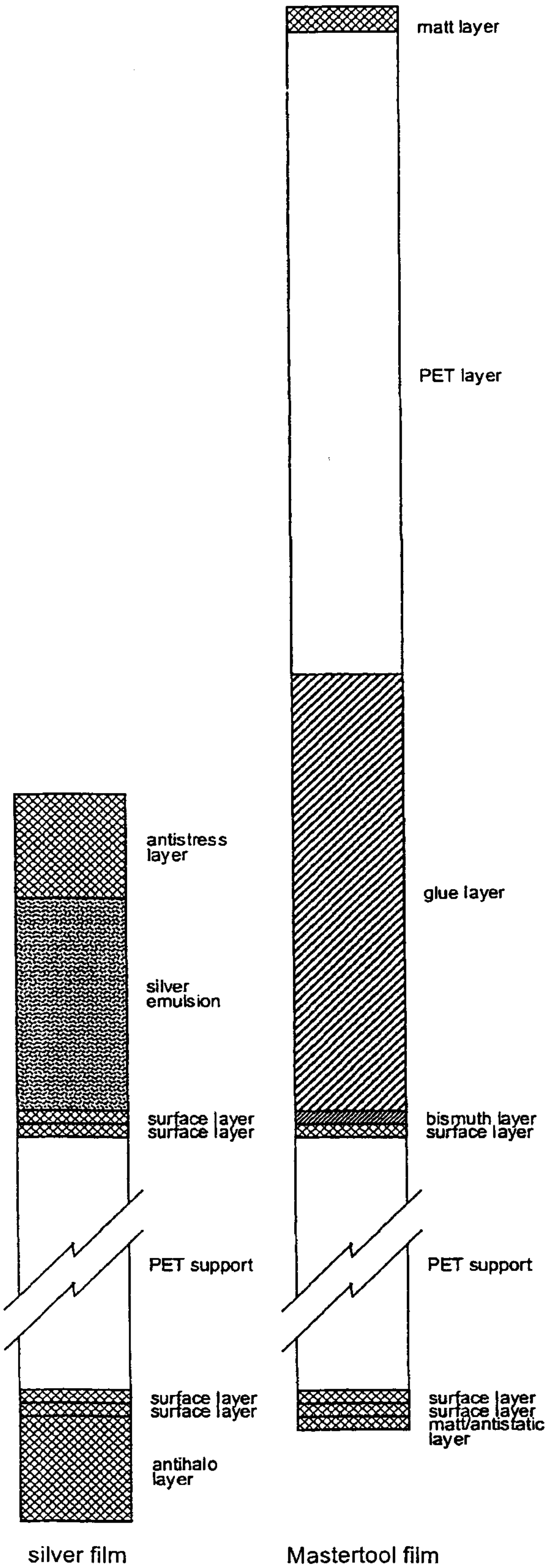

Fig. 1: Structure of silver and Mastertool® film

layer, which serves as the film support. The PET layer is coated on each side with 2 very thin (0.25 µm) layers to give it the desired surface properties. The underside of the film is covered by an antihalo layer (4 µm). A 4 µm thick silver emulsion containing 4.13 g Ag/m^2 film is applied on top of the upper surface layer. The emulsion layer is covered by an antistress layer (2 µm).

The film support for Mastertool® film is a 175 µm thick PET layer, identical to that of silver film. The PET layer is coated with 2 very thin (0.25 µm) layers on the underside, and 1 layer (0.25 µm) on the upper side. A thin metallic bismuth layer (0.25 µm) is applied on top of the upper surface layer. The bismuth layer is protected by a 12 µm thick PET layer, which is applied by means of an 8 µm thick glue layer. The upper side of the film is covered by a thin matt layer (0.5 µm), and the under side by a matt-antistatic layer (0.3 µm).

In order to generate the pattern of the circuit on a silver film, several steps are required [1]. First, the film is exposed to laser light in a photoplotter. During the exposure, the silver changes in a normally invisible way. This change, which is called the latent image, is then made visible by development in a chemical solution. The developing chemicals reduce the exposed silver to its metallic form, but leave the unexposed silver unreduced. After the image is developed, the unreduced silver is removed using chemical fixing agents. Finally, the fixed film is washed with water and dried.

In order to generate the pattern of the circuit on a Mastertool® film, the film only has to be exposed to laser light in a photoplotter [3, 4]. The exposure in the photoplotter causes the bismuth layer to melt locally. During this melting process, the bismuth contracts into microscopic beads. After exposure, the bismuth cools down and solidifies again, but keeps its shape. Because of the empty areas between the beads, the exposed areas of the film are more transparent than the unexposed areas, which results in a stable picture. After exposure, no further chemical processing is necessary.

2.2 Functional unit

The comparison of silver film and Mastertool® film requires an objective basis, the so-called functional unit, which must reflect the function of the investigated products. The definition of the functional unit in this study is based on a typical practical situation in which a manufacturer of printed circuit boards has to produce a batch of 5000 identical single layer eurocards. The dimensions of eurocards are 10 by 16 cm. The phototools that are used to copy the circuit pattern to the eurocards have a standard dimension of 50 by 60 cm, for silver film as well as for Mastertool® film. Keeping account of the fact that some free space is needed between the circuit patterns for the subsequent etching and cutting processes, 1 phototool allows to copy 10 circuit patterns at once. For the production of 5000 single layer eurocards, the phototool thus has to be copied 500 times.

The lifetime of phototools is limited by their susceptibility to mechanical damages (tear and wear) and dimensional changes. In practice, a conventional phototool on the basis of silver can be copied about 100 times. After 100 copies, the phototool has to be replaced by a new one. In order to make 500 copies (the requirement of the functional unit), 5 silver films are thus needed in total. Mastertool® film has a longer lifetime, mainly thanks to the fact that its surface is protected by a PET layer. Mastertool® film can be copied more than 3000 times. This means that the 500 copies for the functional unit can be made with one Mastertool® film. After the 500 copies, the Mastertool® film is in principle still suited for further use, but it is no longer needed because the production of the 5000 single layer eurocards is completed. For the next batch of eurocards that will be produced, a new phototool will have to be used, because these eurocards will contain a different circuit pattern. For the functional unit, the production of a batch of 5000 identical single layer eurocards, either 5 silver films or 1 Mastertool® film are thus needed. Since 1 film has a dimension of 50 x 60 cm or 0.3 m^2, the functional unit corresponds to 1.5 m^2 silver film and 0.3 m^2 Mastertool® film.

2.3 System boundaries

The lifecycle of phototools used in the manufacturing of printed circuit boards, is represented in **Figure** 2 for silver film and in **Figure** 3 for Mastertool® film. The following processes are included in this study:

- the production of the photographic film and of the materials that are required for its production: silver, bismuth, PET and auxiliary substances (all primary materials)
- the packaging of the film and its transport to the producer of printed circuit boards
- exposure of the film in the photoplotter
- chemical processing of the film, production of the used chemicals and of the processor (only relevant for silver film)
- collection and treatment of used film and of photochemical waste (the latter only relevant for silver film)

The production of the photoplotter used for the exposure of the films is left out of the system boundaries. Silver film and Mastertool® film can be exposed using similar types of photoplotters. Only the nature of the light source and the optical devices are different. Therefore, the production of the photoplotter is not expected to have a significant influence on the LCA comparison between silver film and Mastertool®.

The actual use of the films, i.e. the copying of the circuit pattern from the film to the printed circuit boards, is also left out of the system boundaries in this comparative LCA because the involved processes are identical for silver film and Mastertool® film. The difference in lifetimes of both films is taken into account by the definition of the functional unit.

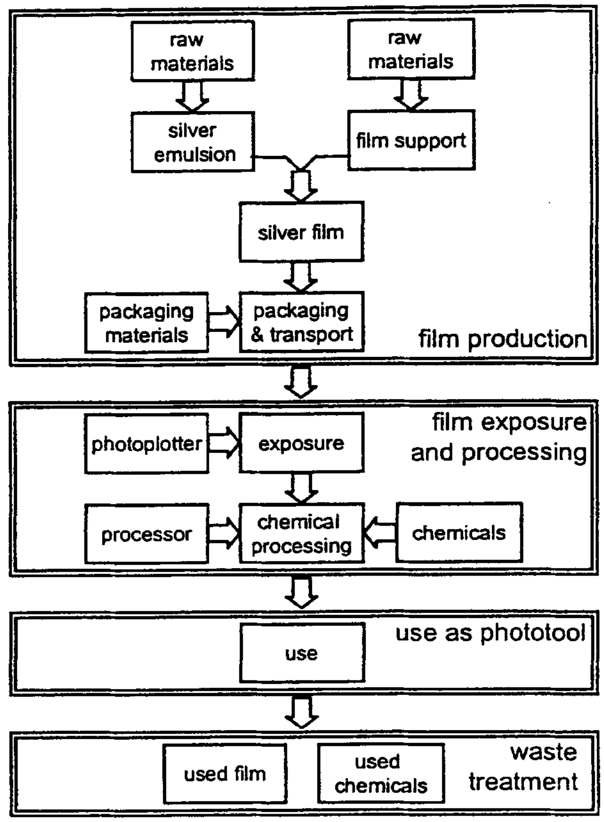

Fig. 2: Lifecycle of silver film

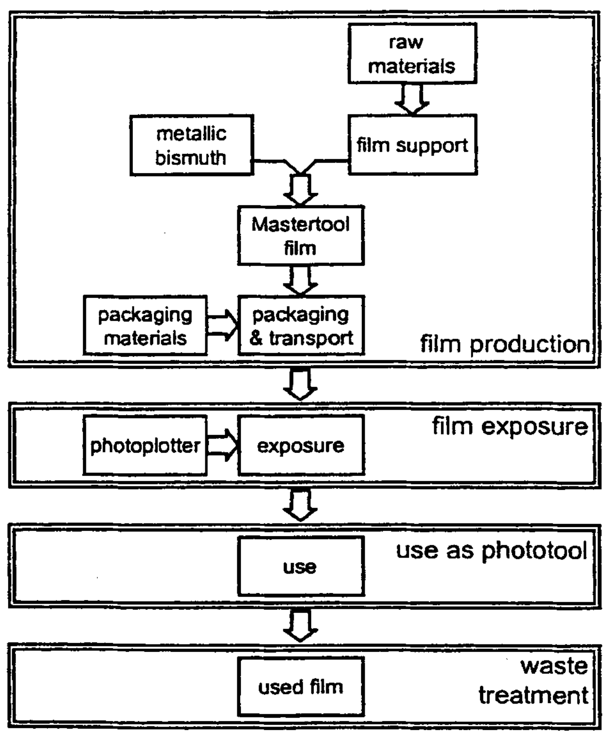

Fig. 3: Lifecycle of Mastertool® film

2.4 Data collection

For the production of silver film and Mastertool® film as well as for the production of the intermediate materials (silver emulsion and film supports) data were collected at the Agfa-Gevaert N.V. production site in Mortsel, Belgium. Agfa-Gevaert N.V. also provided primary data regarding the composition of the film packagings, the energy use of the photoplotters used for the exposure of silver film and Mastertool® film, the amount and composition of the chemicals needed to process the silver film, the emissions during processing, and the composition of the processor.

For the waste treatment of used silver film and used photographic chemicals, data were provided by Argentia N.V., Moerdijk, the Netherlands. Argentia collects photographic waste and recuperates the silver content by electrolysis. The desilvered chemicals are concentrated by vacuum-evaporation and then fed into a glass-oven. In the oven, the organic chemicals are burnt and the inorganic compounds are immobilised in a granulate that can be used in road construction. Desilvered films are burnt with heat recovery.

For the waste treatment of used Mastertool® film, no commercial recycling processes are operated at this moment, although some companies claim that recycling of bismuth from Mastertool® film is technically and economically feasible. In this study, a worst case approach is followed for the waste treatment of used Mastertool® film: it is assumed that the used film is incinerated without bismuth recuperation and without energy recovery.

For the different delivery processes (production of silver or bismuth, PET, photographic chemicals, packaging materials, energy production, transport) secondary data from different literature sources were used. When no specific literature data were found, data for similar or related processes were used instead. For the production of bismuth, average data for the production of other metals were used. For the production of some minor ingredients in the photochemical solutions and in the silver emulsion, data for related chemicals were used. These approximations were justified a posteriori by the results of the analysis, as will be discussed below.

2.5 Results for silver film

The relative energy use of the different phases in the lifecycle of silver film used for the production of printed circuit boards, is given in **Figure 4**.

The results show that the chemical processing of the silver film has a dominant contribution (42%) to the total energy use. This is mainly related to the electricity that is used by the processor, e.g. for pumping and heating the chemicals, for transporting and drying the film etc. The energy needed for the production of the chemicals and the processor itself is also included in the figure of 42%, but is small compared to the energy use of the processor.

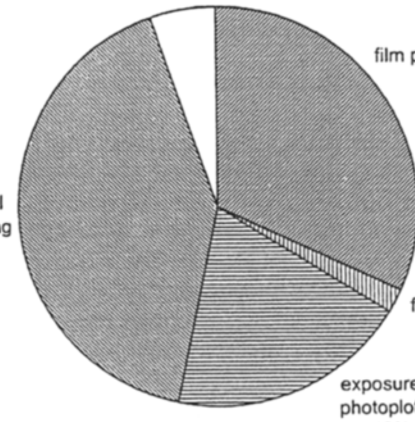

Fig. 4: Energy consumption in the lifecycle of silver film

The exposure of the silver film accounts for about 19% of the total energy consumption, which is explained by the electricity use of the photoplotter.

The production of the film accounts for approximately 32% of the total energy use in the lifecycle of the silver film. About 60% of this energy is used for the actual production of the film (extrusion of the film layers, preparation of the silver emulsion, application of the silver emulsion on the support, cutting of the film). The remaining 40% is used for the production and delivery of the materials that are needed for the film production (PET, silver and auxiliary materials).

The waste treatment of used silver film and used chemicals has a relatively small contribution (5%) to the overall energy use. Packaging and transport only accounts for 2% of the energy use.

In general, a similar picture as for energy use is obtained for other environmental impacts, as is shown in **Figure 5**. For all considered impacts, the major contributions are made by the film production and the chemical processing of the silver film. The exposure of the film in the photoplotter causes relatively smaller, but still significant impacts. The impacts caused by packaging and transport and by the final waste treatment are small or even negligible.

The impact category depletion of inorganic resources is dominated by the use of silver, which is a rare element. A major fraction of the used silver is however recovered during the waste treatment. This explains the negative contribution of this phase of the lifecycle. The contribution of the chemical processing to the depletion of inorganic resources is related to use of metals for the production of the processor.

2.6 Results for Mastertool® film

The relative energy use of the different phases in the lifecycle of Mastertool® used for the production of printed circuit boards, is given in **Figure 6**.

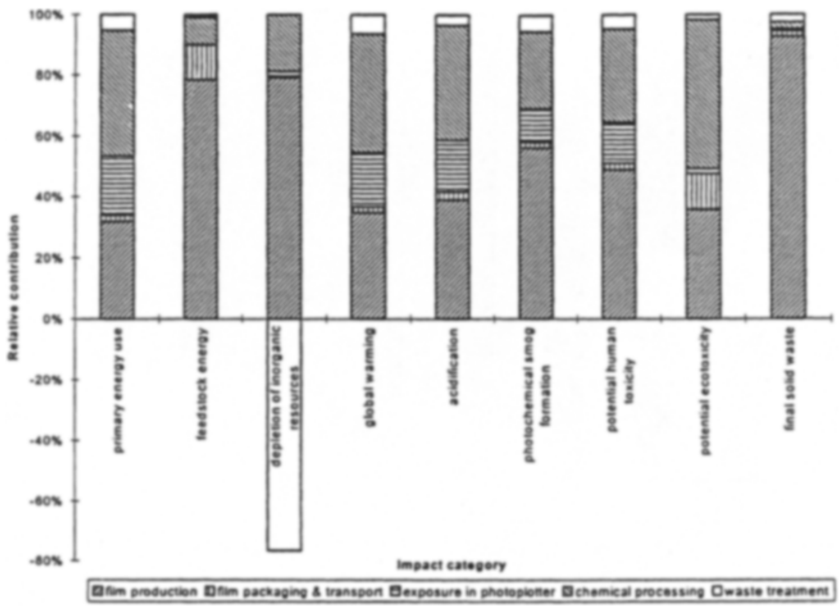

Fig. 5: Environmental impacts in the lifecycle of silver film

For Mastertool® film, the film production has a dominant contribution (68%) to the total energy use. About 65% of this energy is used for the actual production of the film (extrusion of the film layers, applying of the bismuth layer, coating with surface layer, cutting of the film). The remaining 35% is used for the production and delivery of the materials that are needed for the film production (PET, bismuth and auxiliary materials).

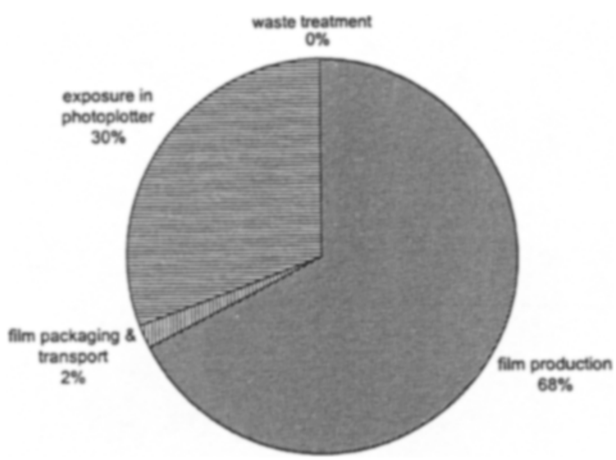

Fig. 6: Energy consumption in the lifecycle of Mastertool® film

The exposure of the Mastertool® film by the producer of printed circuit boards accounts for approximately 30% of the total energy use. This relates completely to the electricity used by the photoplotter.

The energy used for packaging, transport and waste treatment of Mastertool® film is negligible (2%) compared to the energy used in film production and exposure.

In general, a similar picture as for energy use is obtained for other environmental impacts, as is shown in **Figure** 7. For all considered impacts, the major contributions are made by the film production. The exposure of the film in the photoplotter also causes significant, although smaller impacts. The impacts caused by packaging and transport and by the final waste treatment are small or negligible.

2.7 Comparison of silver film and Mastertool® film

The environmental impacts of silver film and Mastertool® film are compared in **Figure** 8. As explained before, the comparison is made for the amount of film that is needed to produce 5000 single layer eurocards.

For all considered environmental aspects, the impacts of Mastertool® film are significantly lower than those of silver film. This is explained by two reasons.

First, Mastertool® film does not need to be chemically processed. This saves a lot of energy, because chemical processing is an energy-consuming step, as was shown by the LCA results for silver film. Furthermore, no chemicals and no processor have to be produced, and no used chemicals have to be treated.

Second, Mastertool® film can be used more often than silver film by a factor of 30. For the functional unit chosen in this comparison, the production of 5000 single layer eurocards, this means that 5 times less film has to be produced, packed and processed in order to manufacture the same amount of printed circuit boards, and that 5 times less film waste is generated. This effect overrules completely the fact that production of Mastertool® film requires more energy and

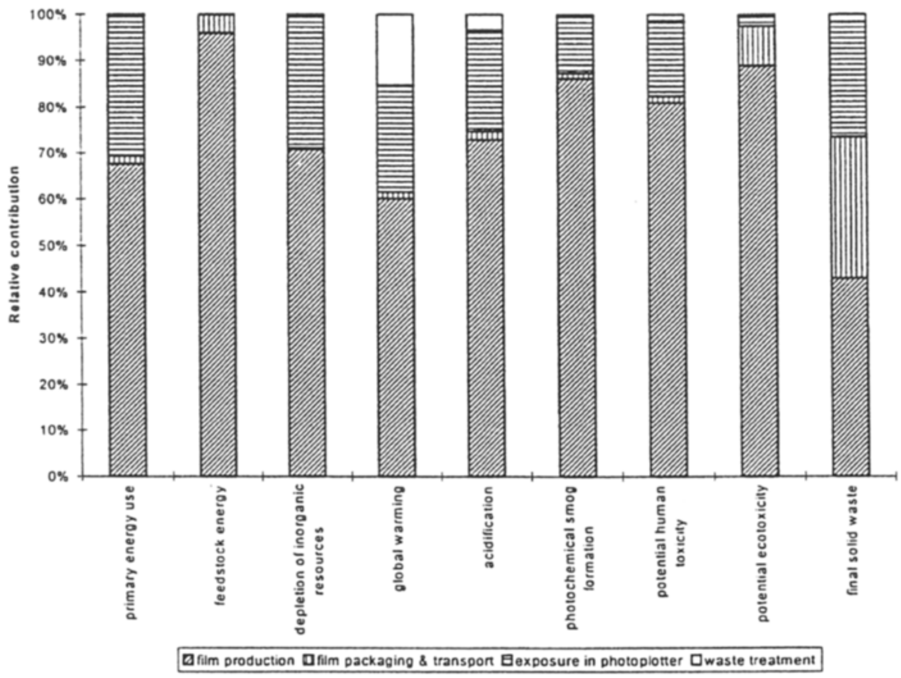

Fig. 7: Environmental impacts in the lifecycle of Mastetool® film

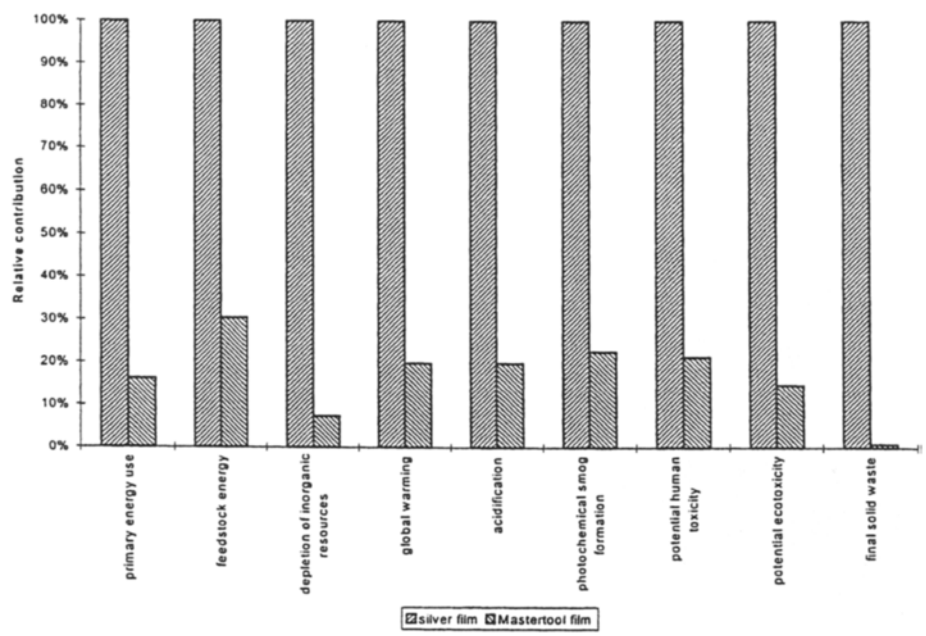

Fig. 8: Comparison of the environmental impacts of silver film and Mastertool® film

more materials than production of the same amount of silver film.

Bismuth and silver are both limited resources. Bismuth is at this moment not recovered from used Mastertool® films, whereas recovery of silver from used silver films and photochemical waste is common practice. Nevertheless, Mastertool® film scores significantly better than silver film for the impact category depletion of inorganic resources. This is partially explained by the fact that bismuth is a less limited resource than silver. Indeed, the static reserve life of bismuth is estimated at 28 years, that of silver at 1 year [5]. Further-

more, the bismuth content of Mastertool® film is significantly lower than the silver content of silver film. Combined with the fact that Mastertool® film has a longer lifetime than silver film, this results in the relatively low contribution to resource depletion for Mastertool® film.

As was mentioned above, low quality data were used in this study for the production of bismuth, for the production of photographic chemicals and for the waste treatment of used Mastertool® film. The results show however that the use of better data would not change the general conclusions of the study. Indeed, the differences between the environmental impacts of silver film and Mastertool® film over their entire lifecycles are so substantial, that the environmental impacts should have been over- or underestimated by at least a factor 3 before the conclusions of the comparison would be reversed. It is highly unlikely that the assessment is that inaccurate, because the processes for which low quality data were used, do not have a dominant contribution to the environmental impacts of the entire lifecycles. For processes which do have a dominant contribution (film production, exposure and processing), high quality, primary data were used. Therefore, it is concluded that the data quality was sufficient in order to reach the goal of the study.

3 Conclusions

This paper presents the results of a comparative LCA between two photographic films that are used as phototools in the printed circuit board industry: a conventional silver film and a new Mastertool® film that allows dry phototooling. During the development of Mastertool®, it was intuitively felt that Mastertool® would have ecological advantages compared to silver film, because no photographic chemicals are needed and no silver containing waste is produced in the printed circuit board production. The comparative LCA confirmed that this is indeed an environmental advantage. It also revealed that the improved technical characteristics of Mastertool®, more specifically its reduced susceptibility to mechanical damages (tear and wear) and its better dimensional stability, which result in an increased lifetime, are at least as important when it comes to reducing the environmental impact of phototools used in the production of printed circuit boards. It took a lifecycle approach to prevent this aspect to be overlooked.

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News & Views

The Nordic Council's Large Nature and Environmental Prize 1997

The prize was granted to the entrepreneur of the **EDIP-Method** (Environmental Design of Industrial Products), that is **The Institute for Product Development (IPU), Technical University of Denmark.**

This was decided at a meeting in Oslo on 18 September 1997. The prize of 350.000 Dkr was presented at the Nordic Council's session in Helsinki on 12 November, 1997.

The IPU was suggested as award winner because of the institute's leading role in the EDIP-programme. During this programme, methods for **Environmental Assessment of Products** and for **Environmentally Design of Products** were developed. The methodology will be supported by a **Unit Process Data Base** and a pc-tool which is still under preparation in a beta version. The methodology is thoroughly tested by five industrial companies and well documented in publications available both in Danish and English. The individual steps of the life cycle assessment have been made operationable through the creation of a collection of tools allowing for environmental assessment of new products in the design and development stages, and thereby enabling the environmental consequences of a product to enter into the decision making in the same way as other traditional commercial parameters.

The programme has already contributed to environmental improvements in a large number of complex industrial products. The companies Bang & Olufsen, Danfoss, Gram, Grundfos and KEW Industry have profited from the programme when using the methodology in product development.

The Institute for Product Development has thus provided a significant contribution to solve the theoretical and practical challenge which both the Nordic countries and the rest of the world are facing to reduce the environmental impacts from consumption of products to ensure a sustainable development.

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